Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**W-OFDM Proposal for the IEEE 802.16.3 PHY**
Date Submitted	**2000-10-29**
Source(s)	Bob Heise Wi-Lan Inc. 300, 801 Manning Rd., Calgary. AB. T2E 8J5. Voice: (403)204-7764 Fax: (403)273-5100 mailto:bobh@wi-lan.com
Re:	Rev 1. This is a response to the IEEE 802.16.3 Task Group, Call for Contributions: Session #10, Topic: Initial PHY Proposals, Ref: IEEE 802.16.3-00/14, dated 2000-09-15. http://ieee802.org/16/sub11/docs/802163-00_14.pdf
Abstract	This document contains a proposal to the IEEE 802.16.3 Task Group for the PHY protocols for a broadband wireless access network standard for licensed bands from 2-11 GHz. This standard is also suitable for unlicensed bands in the 2.4 GHz ISM and 5.7 GHz U-NII unlicensed bands. It is based upon Wideband-Orthogonal Frequency Division Multiplexing (W-OFDM) technology.
Purpose	This document forms the basis and source of a proposed presentation to the IEEE 802.16.3 Task Group at the Working Group Session #10 (6-10 November 2000 in Tampa, Florida, USA).
Notice	
Release	
Patent Policy and Procedures	

Acknowledgements

The following people have contributed to this document:

Adrian Boyer

Lei Wang

Shawn Taylor

Brian Gieschen

Revision History

Release Date	Document Number	Author	Change summary
2000-09-29	TBD	Adrian Boyer	First Draft.
2000-10-18	TBD	Bob Heise	Second Draft.
2000-10-28	TBD	Bob Heise	Third Draft

W-OFDM Proposal for the IEEE 802.16.3 PHY

Bob Heise

Table of Contents

1 Introduction

This document contains a proposal to the IEEE 802.16.3 Task Group for the PHY protocols for a broadband wireless access network standard for licensed bands from 2-11 GHz. This standard is also suitable for unlicensed bands in the 2.4 GHz ISM and 5.7 GHz U-NII unlicensed bands. It is based upon Wideband-Orthogonal Frequency Division Multiplexing (W-OFDM) technology.

1.1 References

The following references have been used during the preparation of this document:

[CALL] IEEE 802.16.3 Task Group, CALL FOR CONTRINUTIONS: Session #10, Topic: Initial PHY Proposals, Deadline: 30 October 2000, dated 2000-09-15, IEEE 602.16.3-00/14.

[FUNCREQ] IEEE 802.16.3 Broadband Wireless Access Working Group, Functional Requirements for the 802.16.3 Interoperability Standard, dated 2000-09-26, IEEE 802.16.3-00/02r4.

1.2 Terminology

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

"MUST" or “SHALL” These words or the adjective "REQUIRED" means that the item is an absolute requirement for any implementation conforming to this standard.

"MUST NOT" This phrase means that the item is an absolute prohibition.

"SHOULD" This word or the adjective "RECOMMENDED" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case care-fully weighed before choosing a different course.

"SHOULD NOT" This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case care-fully weighed before implementing any behavior described with this label.

"MAY" This word or the adjective "OPTIONAL" means that this item is optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

2 Physical Layer

2.1 Overview

The following physical layer specification was designed to meet the functional requirements that have been defined for Broadband Wireless Access (BWA) systems. This physical layer is designed with a high degree of flexibility in order to allow service providers the ability to optimize system deployments with respect to cell planning, cost considerations, radio capabilities, offered services, and capacity requirements.

Two modes of operation have been defined for the downstream channel, one targeted to support a continuous transmission stream and one targeted to support a burst transmission stream. Having this separation allows each to be optimized according to their respective design constraints, while resulting in a standard that supports various system requirements and deployment scenarios.

2.2 Reference Model

Below are two simple reference models that show the general functions of the transmitter and receiver for the OFDM PHY.

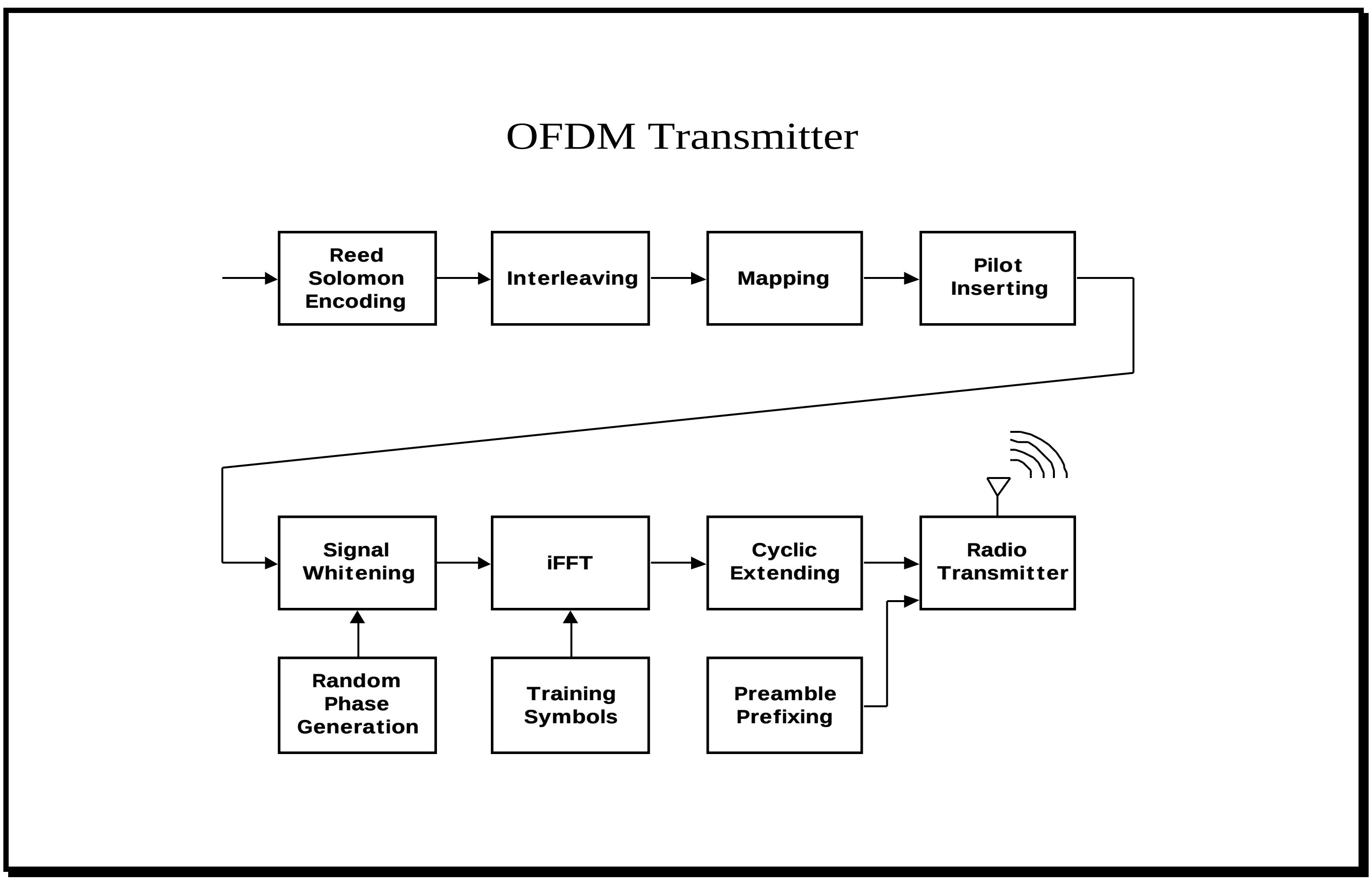

Figure 1: Transmitter Reference Configuration

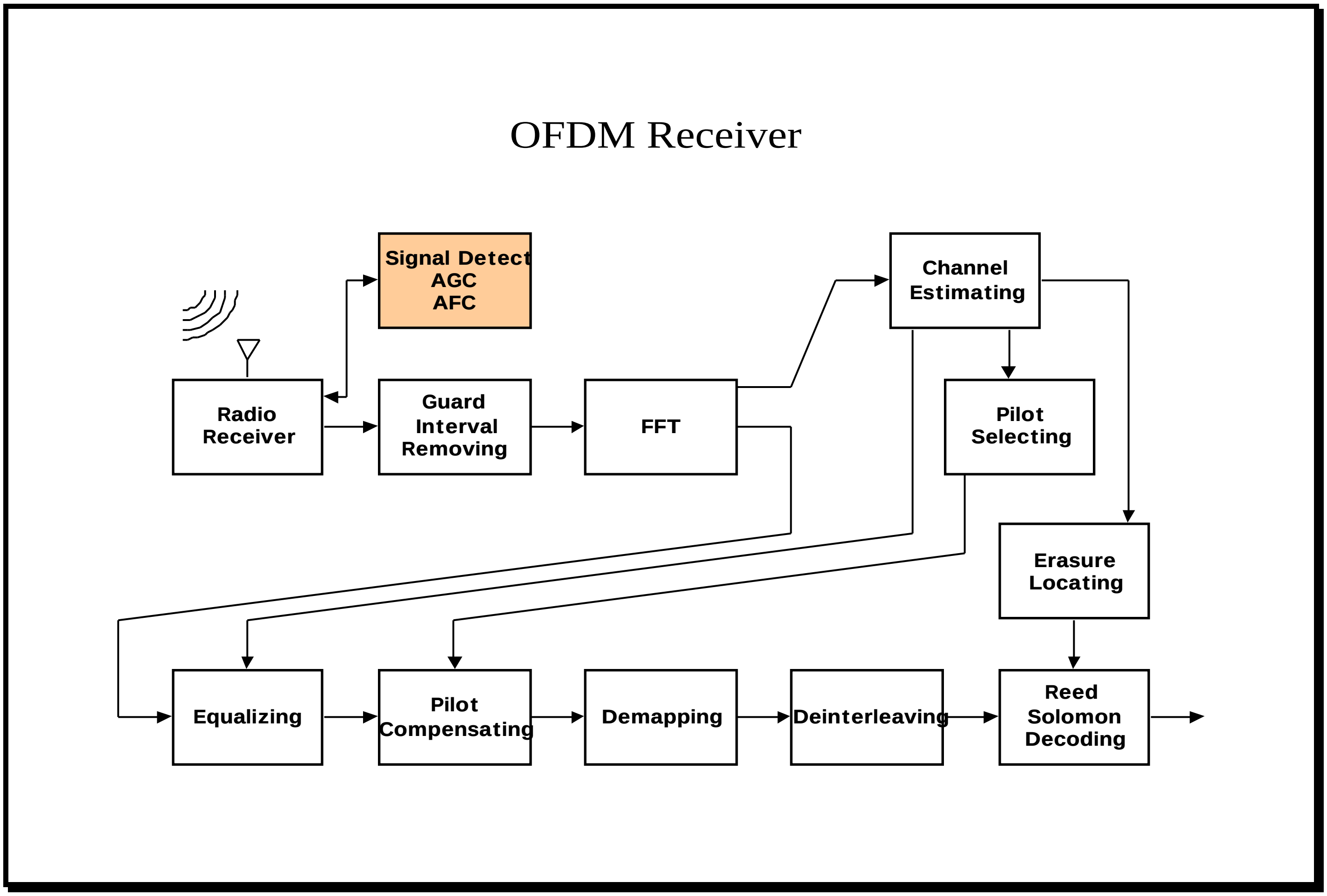

Figure 2: Receiver Reference Configuration

2.3 Reed-Solomon Encoding

The forward error correction (FEC) scheme used in this model is Reed-Solomon (RS). Block coding was chosen specifically to address errors due to multipath fading and subcarrier jamming. The OFDM channel estimation provides useful information, which can be used to determine which RS symbols are likely to be in error. This information can be passed on to the RS decoder to improve the RS correction power.

2.4 Interleaving

The interleaver maps one RS codeword to one or more OFDM data symbols according to the RS symbol size and the mapping scheme. Ideally, each RS symbol is split such that all of its bits are transmitted on one OFDM subcarrier frequency. This is done to take advantage of the block correcting nature of the RS decoder in the presence of multipath fading or subcarrier jamming.

2.5 Mapping

The subcarrier modulation mapping will be BPSK, QPSK, 16QAM, or 64QAM. 256QAM should also be evaluated. A Gray coded constellation mapping is recommended.

2.6 Pilot Insertion

Each OFDM data symbol must contain pilot signals in order to recover the proper constellation magnitudes and the proper constellation phases. Constellation phase rotations are caused by carrier offsets.

2.7 Random Phase Generation

This function creates a set of Random Phase Vectors, which are used to whiten the transmitted signal.

2.8 Signal Whitening

Each mapped data point is multiplied by a random phase. This is done to reduce the peak-to-average power ratio of an OFDM data symbol.

2.9 iFFT

The inverse FFT transforms the data from the frequency domain into the time domain for transmission over the RF channel. Two FFT sizes are proposed and will be selectable depending upon the channel characteristics. The proposed FFT sizes are 64 points, and 256 points.

2.10 Training Symbols

The random phase vectors are used as training symbols. The same training symbol is sent several times to provide a measure of noise immunity to the channel estimation. The receiver uses these training symbols to perform the channel estimation.

2.11 Cyclic Extending

Each time-domain OFDM data symbol is extended, by copying a portion from one end of the symbol to the other. This is done to make the OFDM data robust against multipath delays. The length of the extension will be selectable over a range of samples.

2.12 Preamble Prefixing

A preamble must be added to each OFDM packet. The receiver uses the preamble for:

- Packet synchronization
- Automatic Gain Control (AGC)
- Carrier Frequency Offset Compensation

It can also be used for signaling certain PHY parameters such as the FFT size.

2.13 Channel Estimating

This function creates an equalization vector by taking the complex reciprocal of each subcarrier in the average OFDM training symbol. It also creates a subcarrier magnitudes vector, which can be used by the Pilot Selecting function and the Erasure Locating Function.

2.14 Pilot Selecting

The magnitudes vector created by the channel estimator is used to determine which pilot symbols should be used in the pilot compensation. If some pilots are in deep fades while others are not, then the pilots in deep fades should not be used in the pilot compensation algorithm.

2.15 Erasure Locating

The magnitudes vector created by the channel estimator is used to determine which RS symbols within an RS codeword are likely to be in error. If some RS symbols are deemed much more likely to be in error, they can be erased, and if they are in fact in error, then the correction power of the RS decoder can be increased.

2.16 Equalizing

Each OFDM data symbol is equalized, in an attempt to restore the relative position of each constellation point with respect to the pilot symbols. This process will compensate each subcarrier on an individual basis as well as undo the phase randomization.

2.17 Pilot Compensating

Pilot compensation attempts to recover the transmitted constellation on the receiver.

2.18 OFDM Frame Format

The format of the OFDM frame is depicted below.

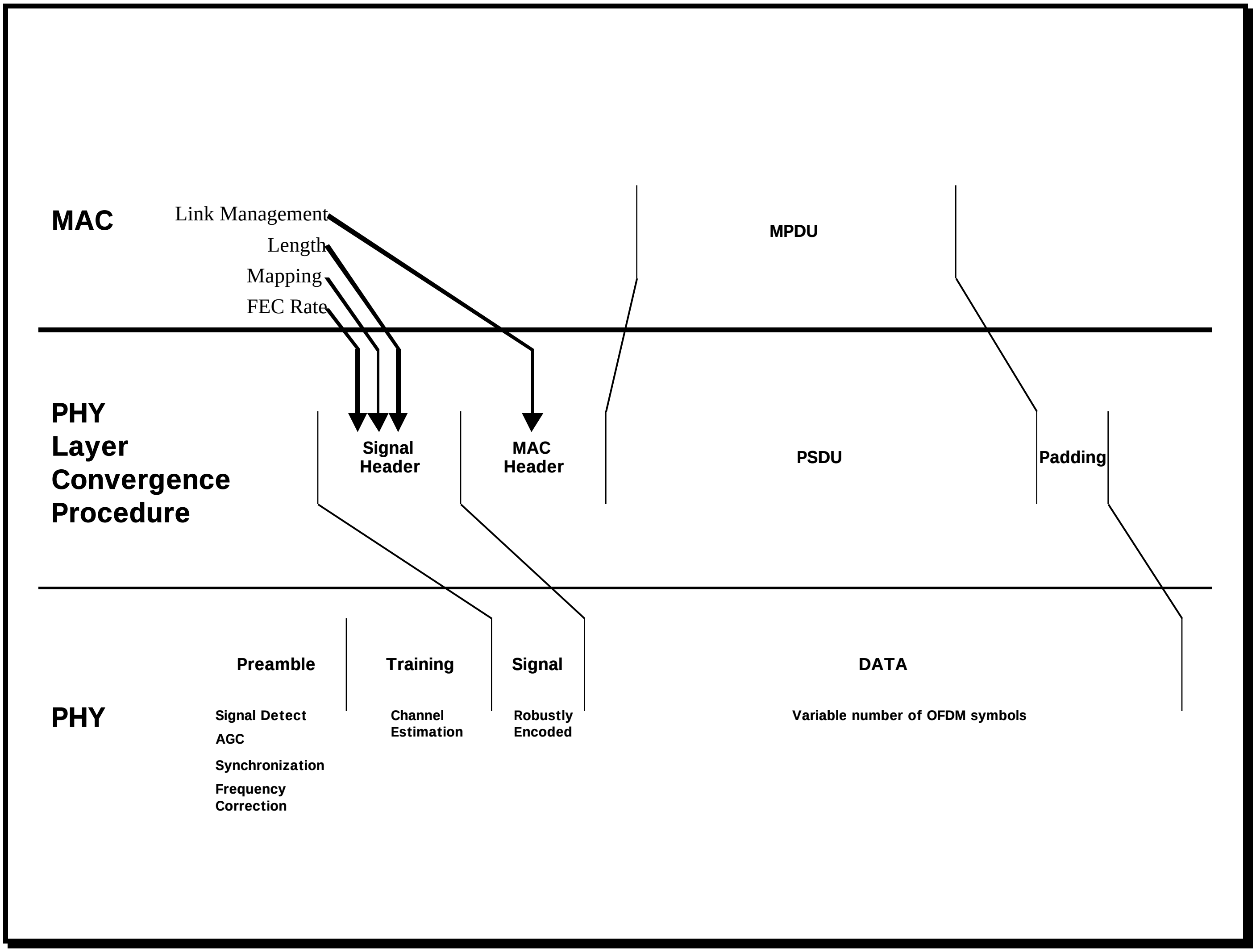

Figure 3: OFDM Frame Format

2.19 Upper Layer Interfaces

The MAC should send the following information to the PHY:

- Data Length
- Data
- Modulation (Mapping) Rate
- FEC Rate
- Tx Power
- Tx Time
- Tx Center frequency
- Rx Center frequency

The PHY should send the following information to the MAC

- Data Length
- Data
- RSSI
- BER
- Rx Time

2.20 Channel and Data Rate Analysis

The PHY supports various channel sizes. The supported channels are 1.75, 3.5, and 7MHz, and 1.5 to 25MHz. The channel size is selected by adjusting the system clock.

A performance analysis for a 3MHz channel, of the two FFT sizes, with the various recommended modulation and coding rates is presented in the table below. The performance of channel sizes will almost be proportional to channel size. Only the guard interval prevents the data rate from being directly proportional to the channel size.

Channel Size (MHz)	OFDM FFT Size	Data Subcarriers	Pilots per Symbol	Coding Rate	Mapping	Coded Bits per Subcarrier	Coded Bits per OFDM symbol	Guard Interval (μs)	Data Rate (Mbit/s)
3.00	64	48	4	3/4	BPSK	1	48	2.00	1.542857
3.00	64	48	4	3/4	QPSK	2	96	2.00	3.085714
3.00	64	48	4	3/4	16QAM	4	192	2.00	6.171429
3.00	64	48	4	3/4	64QAM	6	288	2.00	9.257143
3.00	256	216	8	23/27	BPSK	1	216	2.00	2.106870
3.00	256	216	8	23/27	QPSK	2	432	2.00	4.213740
3.00	256	216	8	23/27	16QAM	4	864	2.00	8.427481
3.00	256	216	8	23/27	64QAM	6	1296	2.00	12.641221

Figure 4: Performance Analysis of 3MHz Channel

3 Summary

3.1 Benefits of PHY

- OFDM is very spectrally efficient. This is very important with the RF spectrum becoming increasing crowded.
- OFDM can be used in TDD or FDD modes of operation.
- OFDM can be easily configured for various channel characteristics.
- OFDM is robust to channel impairments caused by multipath.
- Reed-Solomon with erasures complements OFDM very well, especially when the RF channel is non-ideal. Occurrences of errors due to multipath nulls or jammers may be predictable and erasable.
- Reed-Solomon provides quality of service information based on the occurrence of correctable errors. This may allow the link data rates to be adjusted and optimized without any uncorrectable errors occurring.
- OFDM is already used in other standards. Ultimately this will result in low cost implementation alternatives.

3.2 Drawbacks of PHY

The nature of the orthogonal encoding gives rise to high peak-to-average signals; or in other words, signals with a large dynamic range. This means that only highly linear, low-efficiency RF amplifiers can be used.

3.3 Comparison to Existing Standards

This proposed standard is similar to IEEE 802.11a and ETSI HIPERLAN Type 2, in that it is based on OFDM. The main differences are:

- Longer guard interval
- Larger FFT size
- Reed-Solomon FEC
- Configurable channel sizes

4 Intellectual Property Rights

Wi-LAN offered to license its W-OFDM technology in July 1998 to all interested parties on fair, reasonable and non-discriminatory terms. See US patent number 5,282,222.

Appendix A: Acronyms and Abbreviations

ATDD	Adaptive Time Division Duplexing
BR	Bandwidth Request
BS	Base Station
CG	Continuous Grant
CID	Connection Identifier.
CPE	Customer Premises Equipment (equivalent to SS)
CS	Convergence Subprocess
CSI	Convergence Subprocess Indicator
CTG	CPE Transition Gap
DAMA	Demand Assign Multiple Access
DES	Data Encryption Standard
DL	Down Link
DSA	Dynamic Service Addition
DSC	Dynamic Service Change
DSD	Dynamic Service Deletion
EC	Encryption Control
EKS	Encryption Key Sequence
FC	Fragment Control
FDD	Frequency Division Duplex
FSN	Fragment Sequence Number
GM	Grant Management
GPC	Grant Per Connection
GPT	Grant Per Terminal
HCS	Header Check Sequence
H-FDD	Half-duplex FDD
HL-MAA	High Level Media Access Arbitration
HT	Header Type
IE	Information Element
IUC	Interval Usage Code
LL-MAA	Low Level Media Access Arbitration
MAC	Medium Access Control
MIC	Message Integrity Check

MPDU	MAC Protocol Data Unit
MTG	Modulation Transition Gap
OFDM	Orthogonal Frequency Division Multiplexing
PCD	Physical Channel Descriptor
PBR	Piggy-Back Request
PDU	Protocol Data Unit
PHY	Physical layer
PI PHY	PHY Information element
PKM	Privacy Key Management
PM	Poll Me bit
PS	Physical Slot
PSDU	Physical sublayer Service Data Unit
QoS	Quality of Service
RS	Reed-Solomon
SAP	Service Access Point
SI	Slip Indicator
SDU	Service Data Unit
SS	Subscriber Station
TC	Transmission Convergence
TDD	Time Division Duplex
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
TDU	TC Data Unit
TLV	Type-Length-Value
TRGT	Tx/Rx Transmission Gap
UGS	Unsolicited Grant Service
UGS-AD	Unsolicited Grant Service with Activity Detection
UL	Link
W-OFDM	Wideband - Orthogonal Frequency Division Multiplexing